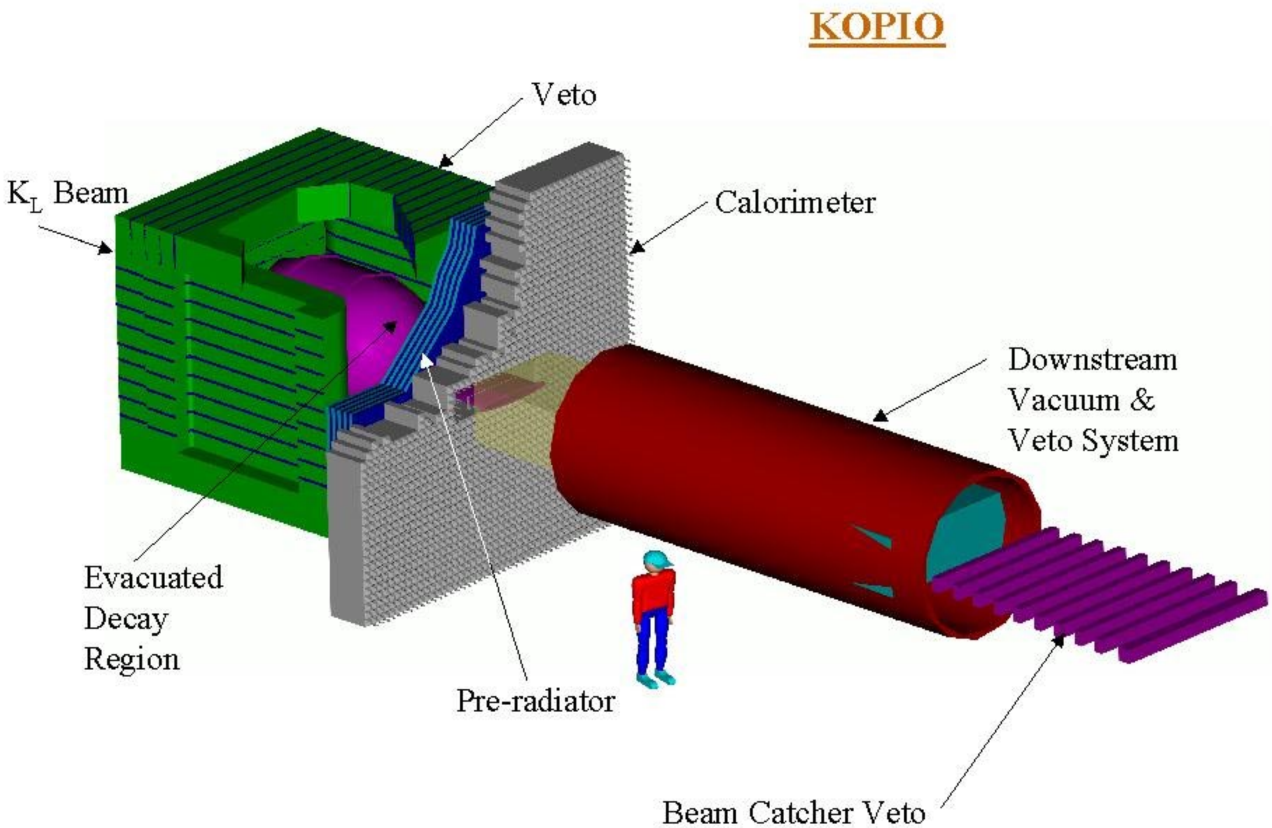
KOPIO $K_L \to \pi^0 \nu \bar{\nu}$ Experiment

L. Littenberg - BNL

20 April 2001



HEPAP Subpanel on Long Range Planning for U.S. High Energy Physics

KOPIO - a search for $K^0 \to \pi^0 \nu \bar{\nu}$

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KOPIO

$K_L \to \pi^0 \nu \bar{\nu}$ is a clean window into the heart of CP violation
- directly determines the height of the unitarity triangle
- complementary to B system results (e.g. does $\eta_B = \eta_K$?)

KOPIO designed to collect ~ 50 evts with low bckgnd in 3 yrs
- can give $7 - 8\%$ measurement of $Im\lambda_t$

Can explore a window from $\sim 6 \times 10^{-7}$ down to $\sim 10^{-12}$
- less than 1% of which is allowed by S.M.

Technique exploits favorable conditions available at AGS
- intense, μ-bunched beam
- running incremental to RHIC

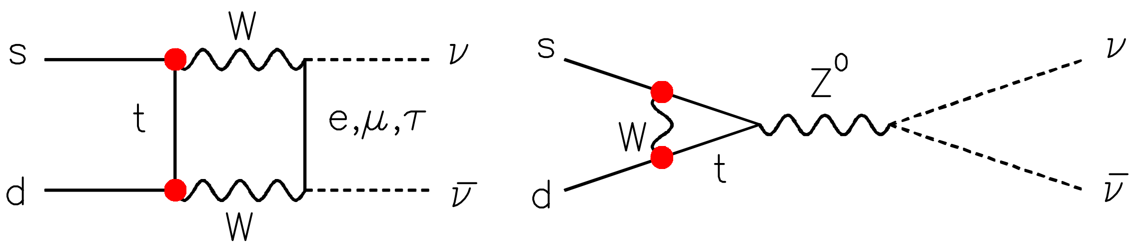
Features highly effective constraints and cross-checks
Has been through several reviews

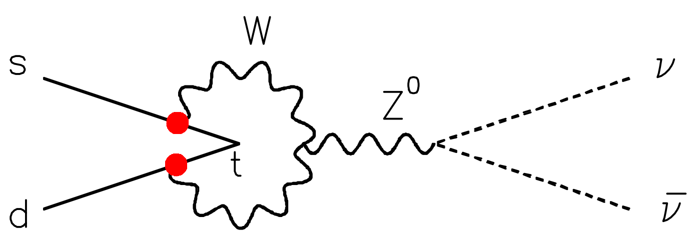
KOPIO capitalizes on experience (& personnel) of past exps
- AGS E787: similar vetoes, analysis techniques
- AGS E865: similar rates, calorimetry

Practical, cost effective, solutions for the technical challenges
- instrumentation based on existing detectors where possible
  or, where necessary, on tested prototypes

Capital & operating costs to be funded by NSF

$K_L \to \pi^o \nu \bar{\nu}$ in the Standard Model





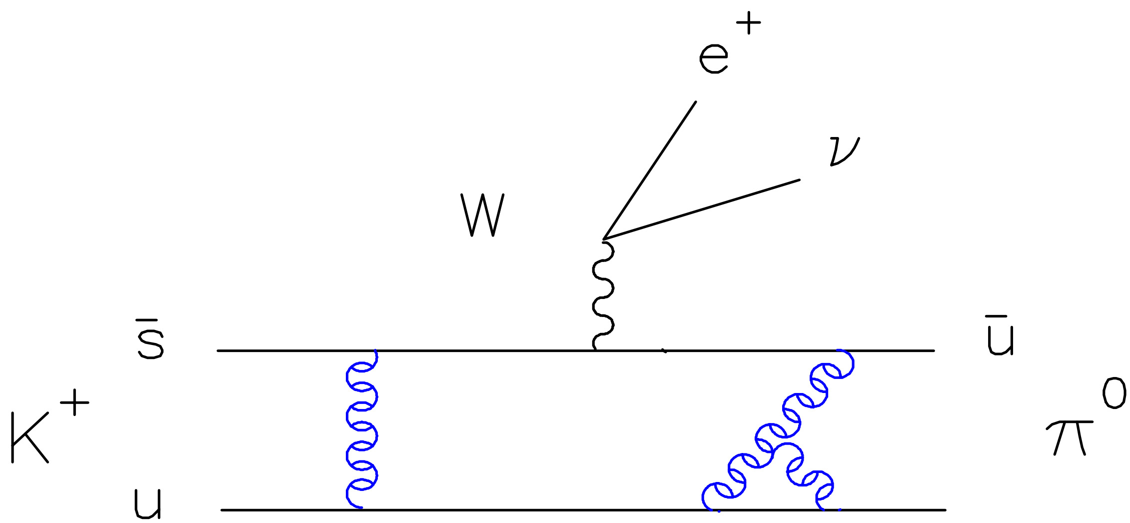
$$B\left(K_L \to \pi^o \nu \bar{\nu}\right) \quad = \quad r_{K_L} \; \frac{\tau_{K_L}}{\tau_{K^+}} \; \frac{\alpha^2 B\left(K^+ \to \pi^o e^+ \nu\right)}{V_{us}^2 2\pi^2 sin^4\theta_W} \; \sum_l \left| Im V_{ts}^* V_{td} X\left(x_t\right)\right|^2$$

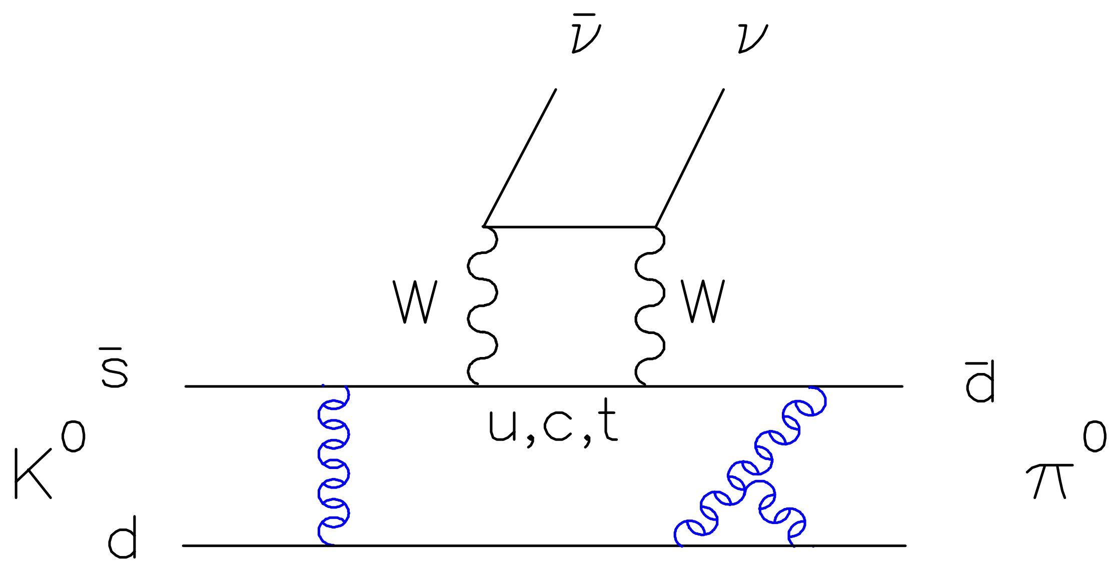
no. significant QCD corr.

$$= (3.1 \pm 1.3) \times 10^{-11} \quad \text{(recent CKM fit)}$$

r_{K_L} is correction of $B\left(Ke_3\right)$ for isospin, phase space, etc. $=$ 0.944

K Hadronic Matrix Element





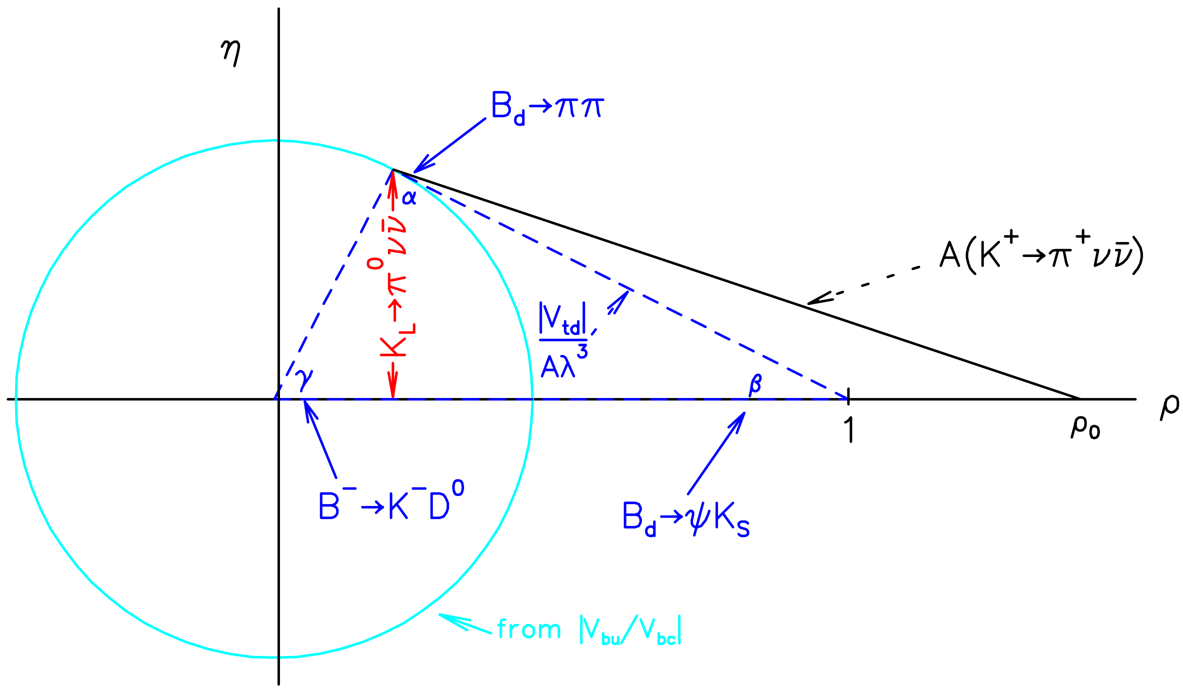
$K_L \to \pi^0 \nu\bar{\nu}$ in the Standard Model

Pure direct CP-violating (state-mixing very small)

Calculation in terms of fundamental parameters good to $\lesssim 2\%$

In terms of usual unitarity triangle parameterization:

$$B(K_L \to \pi^0 \nu\bar{\nu}) = 4 \cdot 10^{-10} A^4 \eta^2$$



Gives height of UT without triangulation

- with $K^+ \to \pi^+ \nu\bar{\nu}$ can determine ρ as well

Also note that

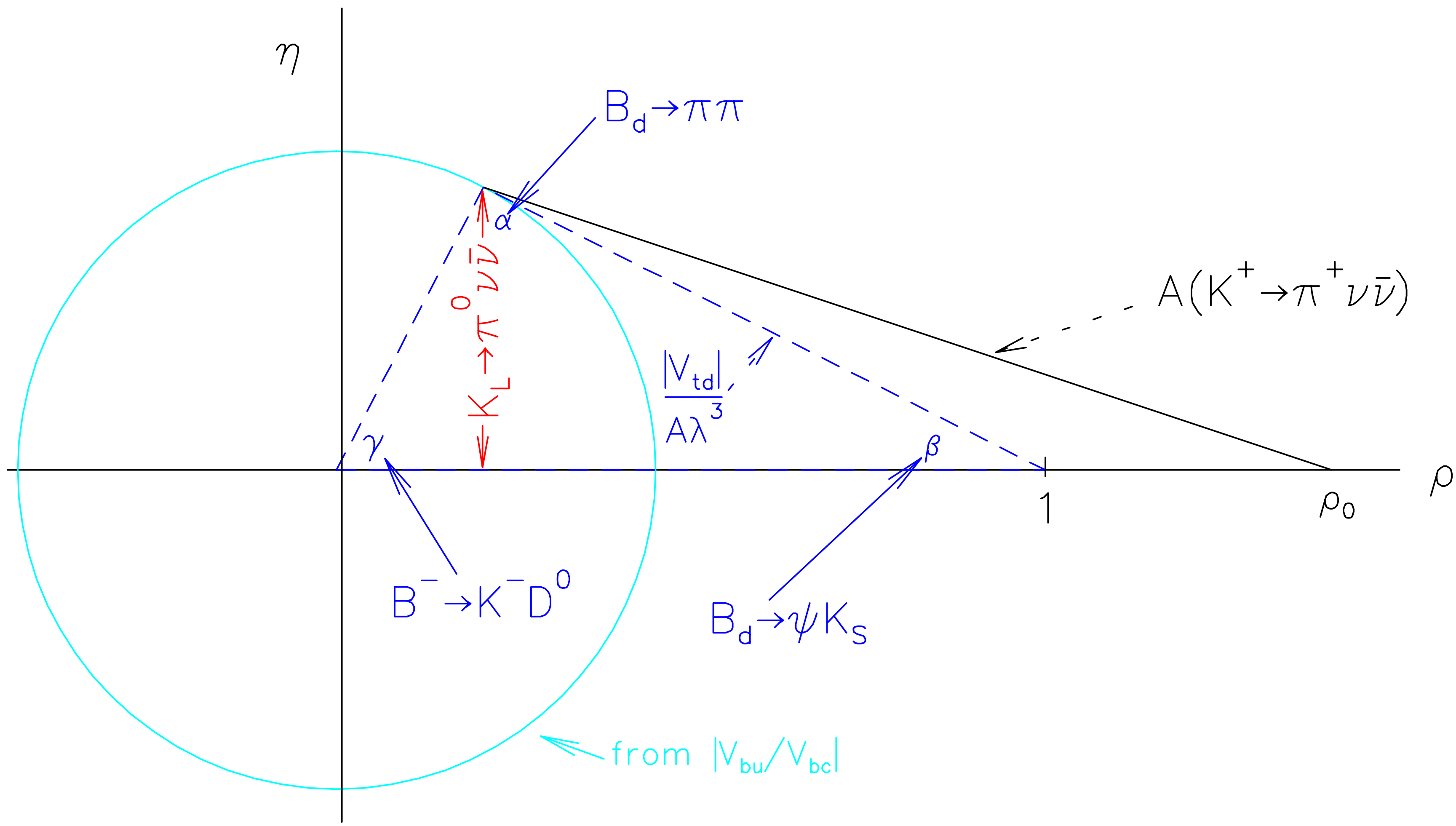
$$B(K_L \to \pi^0 \nu\bar{\nu}) = 1.56 \cdot 10^{-4} [Im(V_{ts}^* V_{td})]^2 \equiv 1.56 \cdot 10^{-4} [Im\lambda_t]^2$$

$Im\lambda_t$ presently triangulated to $\sim 22\%$,

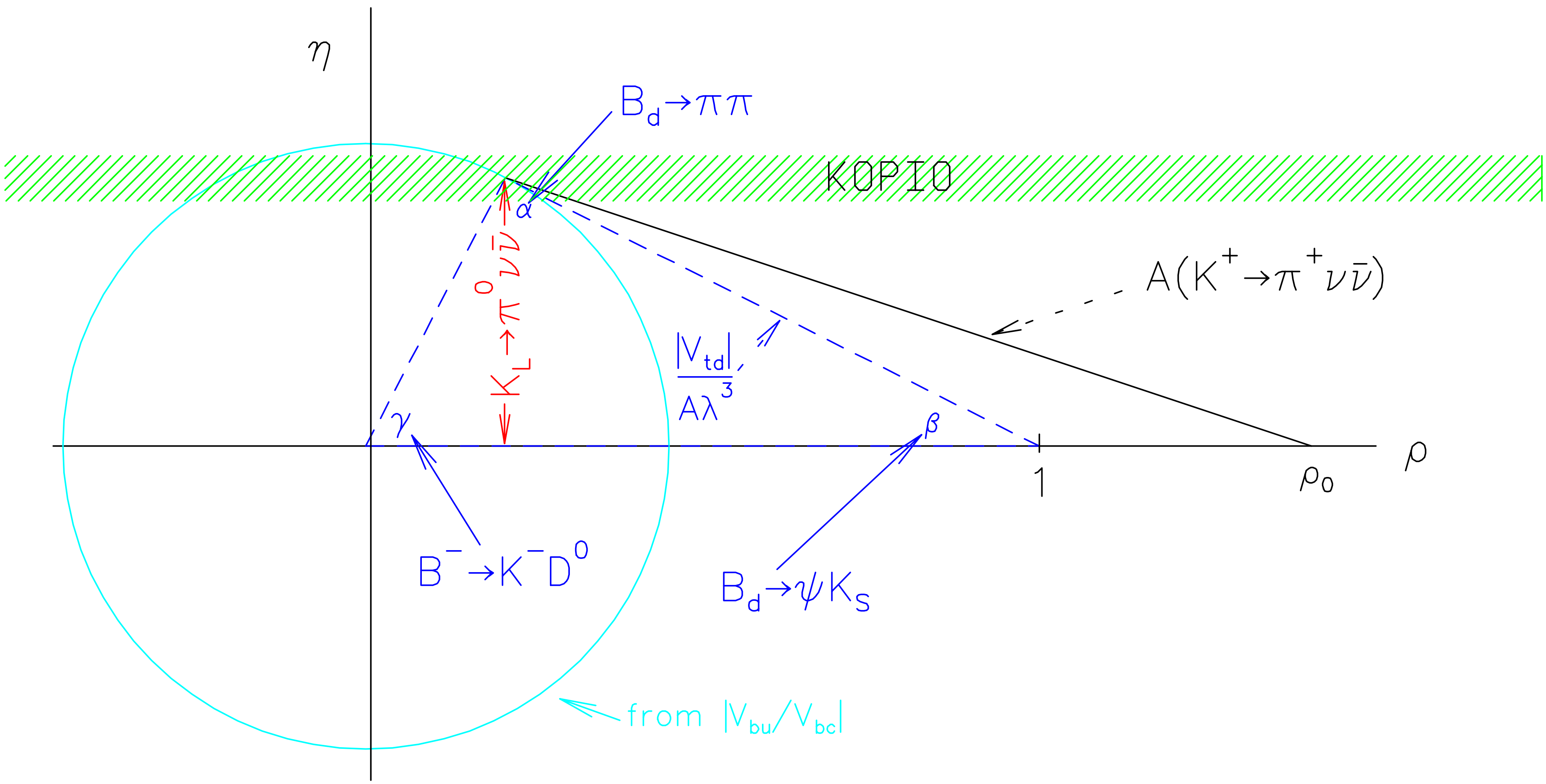
- KOPIO could directly measure it to $7-8\%$

There are only a few solid measurements on the UP

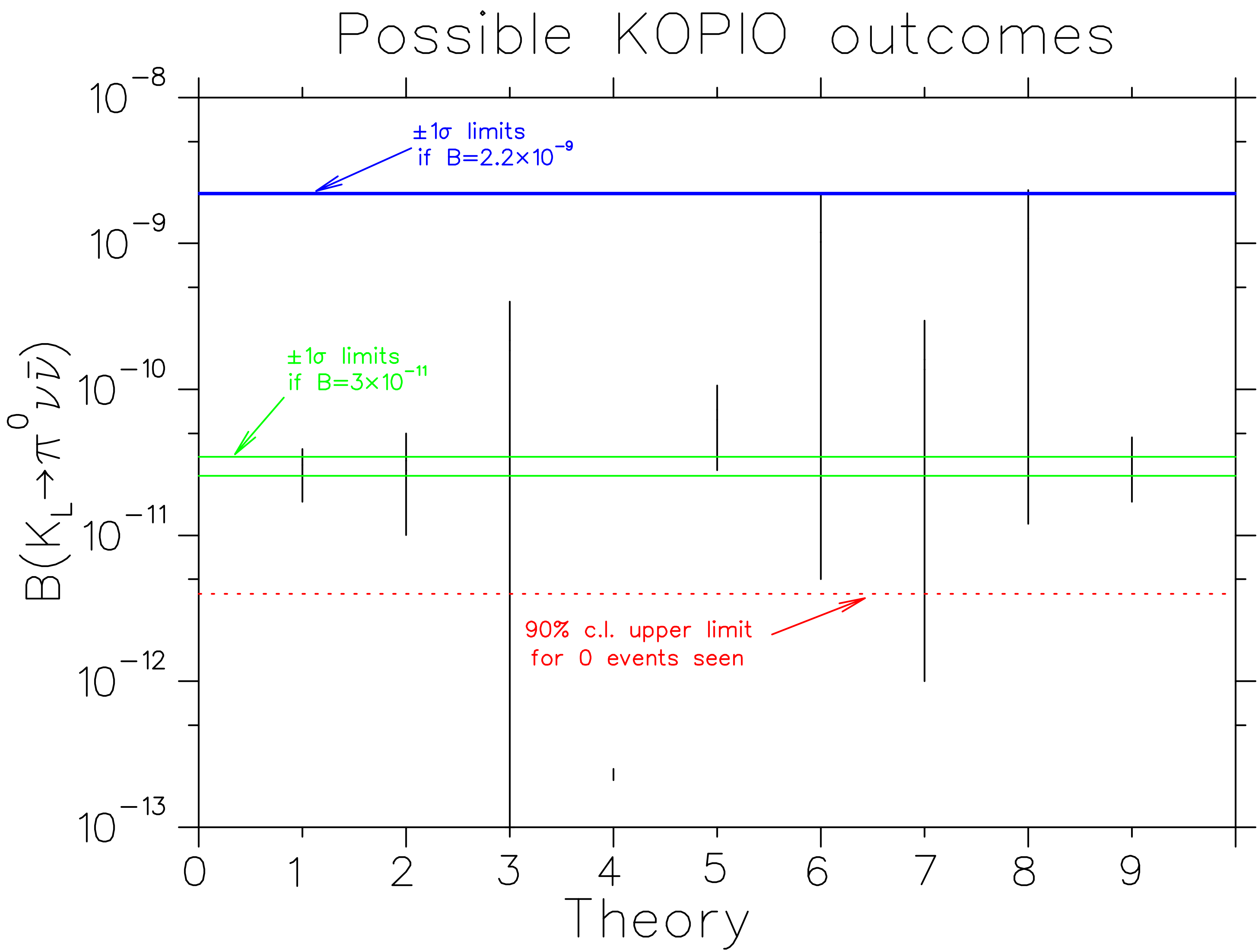
- none is better!



η
$B_d \to \pi\pi$
α
$K_L \to \pi^0 \nu\bar{\nu}$
$A(K^+ \to \pi^+ \nu\bar{\nu})$
$\frac{|V_{td}|}{A\lambda^3}$
γ
β
ρ
1
ρ_0
$B^- \to K^- D^0$
$B_d \to \psi K_S$
from $|V_{bu}/V_{bc}|$



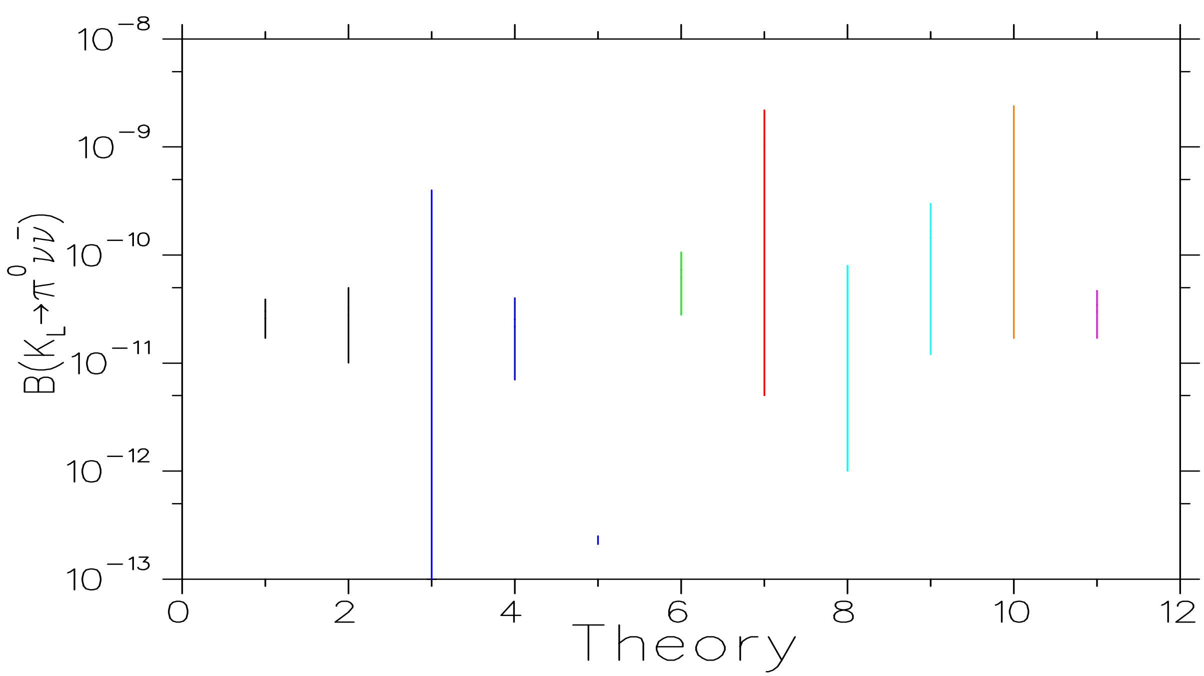
η
$B_d \to \pi\pi$
KOPIO
α
$K_L \to \pi^0 \nu\bar{\nu}$
$A(K^+ \to \pi^+ \nu\bar{\nu})$
$\frac{|V_{td}|}{A\lambda^3}$
γ
β
1
ρ_0
ρ
$B^- \to K^- D^0$
$B_d \to \psi K_S$
from $|V_{bu}/V_{bc}|$


Possible KOPIO outcomes
±1σ limits
if B=2.2×10^-9
±1σ limits
if B=3×10^-11
90% c.l. upper limit
for 0 events seen
B(K_L→π^0 νν̄)
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
0
1
2
3
4
5
6
7
8
9
Theory

$K_L \to \pi^0 \nu\bar{\nu}$ Beyond the Standard Model

	Who	What	$10^{11} B(K_L \to \pi^0 \nu\bar{\nu})$
1	Buchalla	Standard Model CKM fit	2.8 ± 1.1
2	Plaszczynski/Schune	Conservative SM fit	$1 - 5$
3	Buras, *et al.*	Generic SUSY w/min. part. content	$0 - 40$
4	Buras, *et al.*	MSSM w/o new flavor or CP viol.	$(0.41 - 1.03)\times$ SM
5	Brhlik, *et al.*	all CP-viol. due to SUSY	$\sim .023$
6	Chanowitz	$SU(2)_L \times SU(2)_R$ Higgs	$2.8 - 10.6$
7	Hattori, *et al.*	4th generation	$0.5 - 220$
8	Xiao, *et al.*	top-color assisted technicolor	$0.1 - 8$
9	Xiao, *et al.*	multiscale walking technicolor	$1.2 - 30$
10	Grossman/Nir	Extra "vector-like" quarks	$1.7 - 240$
11	Kiyo, *et al.*	seesaw L-R model†	$(1 - 1.2)\times$ SM

† predicts spectrum will be altered.



A Model Independent Limit on $B(K_L \to \pi^0 \nu\bar{\nu})$

$B\left(K_L \to \pi^0 \nu\bar{\nu}\right) < 4.4 \times B\left(K^+ \to \pi^+ \nu\bar{\nu}\right)$

Proposed by Y. Grossman & Y. Nir

- Phys. Lett. **B398**, 163 (1007)

A consequence of $\Delta I = \frac{1}{2}$ rule

- trivial in SM

- true in for almost any short-distance interaction even if that interaction conserves CP

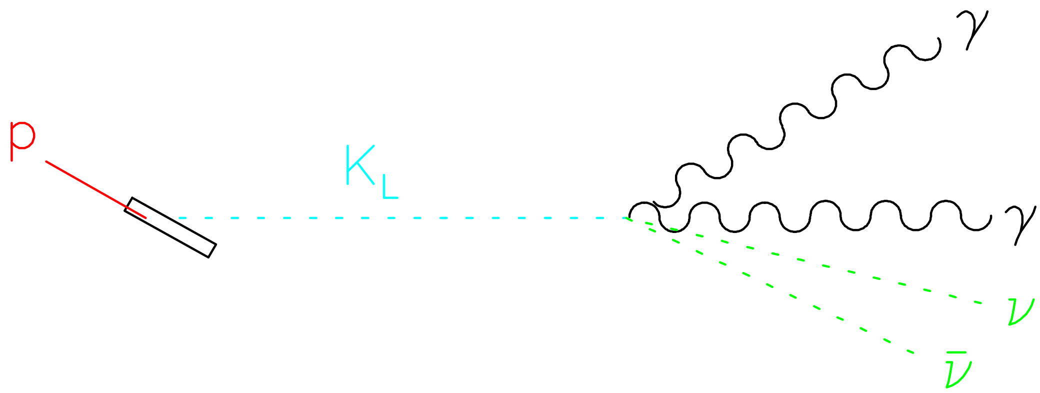
New E787 result is $B\left(K^+ \to \pi^+ \nu\bar{\nu}\right) = \left(1.5^{+3.4}_{-1.2}\right) \times 10^{-10}$

This leads to $B\left(K_L \to \pi^0 \nu\bar{\nu}\right) < 2.2 \times 10^{-9}$ at 90% c.l.

Far better than any other current limit

- but still 100 times larger than SM expectation

$K_L \to \pi^0 \nu\bar{\nu}$ experimental issues



All neutral initial & final state, γ's make π^0

Expected branching ratio 3×10^{-11}
- need high flux of K_L

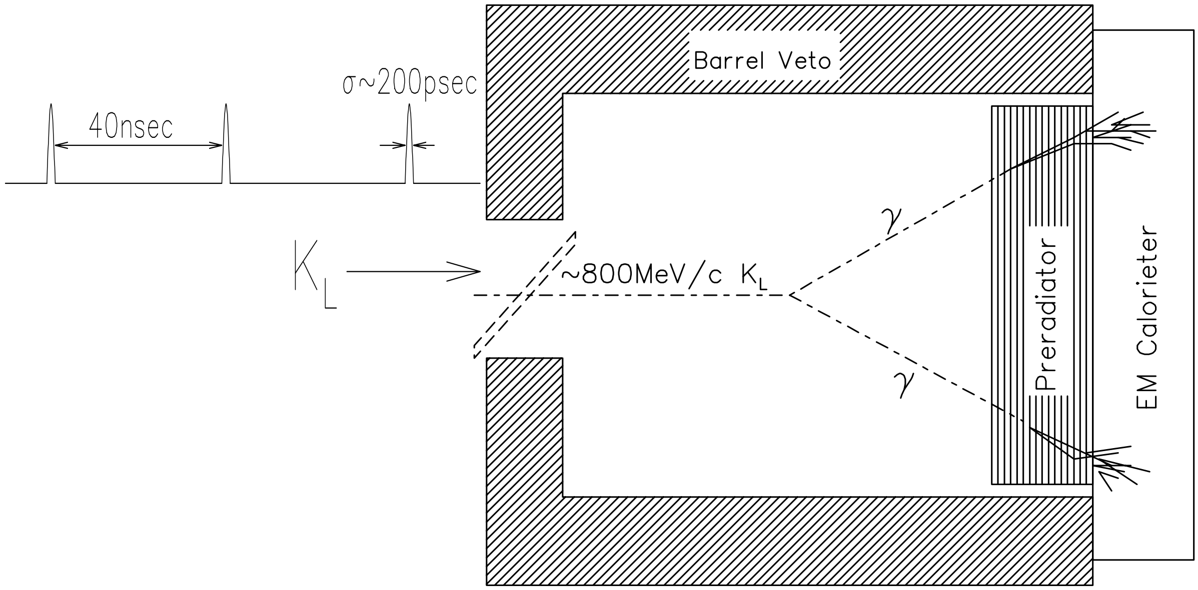
Largest background $K_L \to \pi^0\pi^0$, BR $\sim 10^{-3}$
- need excellent vetoing, other handles if possible

Background from neutron-produced π^0's, η's
- requires vacuum of 10^{-7}
- need to make sure decay vertex was in beam

Potential backgrounds from hyperon decay π^0's
- could use a clever way of getting rid of them

Present status: $B(K_L \to \pi^0 \nu\bar{\nu}) < 5.9 \times 10^{-7}$
- from KTeV, using Dalitz-converted π^0's

Principles of KOPIO



Veto hermetically

E787-type veto + beam "catcher"

All possible initial & final state quantities measured

μ−bunched, large ∠ (low p) beam for K_L TOF

Preradiator to measure γ directions (gives vertex)

+ calorimeter, get energies, times

Work in the K_L center of mass system

K_L TOF makes this possible

This allows kinematic suppression of backgrounds

Measure backgrounds

Kinematic handle allows one to do this

Very hard to *simulate* background at 10^{-11} level

Advantages of KOPIO Technique

Vertex positively determined
- know the 2 γ's from a single source in the beam
- determine the K_L direction

4C fit to π^0
- sure of ID
- get improved kinematics

Can require π^0 consistent with $K_L \to \pi^0 \nu \bar{\nu}$
- can cut on $p^*_{\pi^0}$ as well as p_T

Can avoid configuration with low energy missed γ's
- since $E_{missing}$ can be determined
- makes photon veto requirement less onerous

Reduced background from K_L decay & other sources
- kinematic handle useful for most K decays, n's

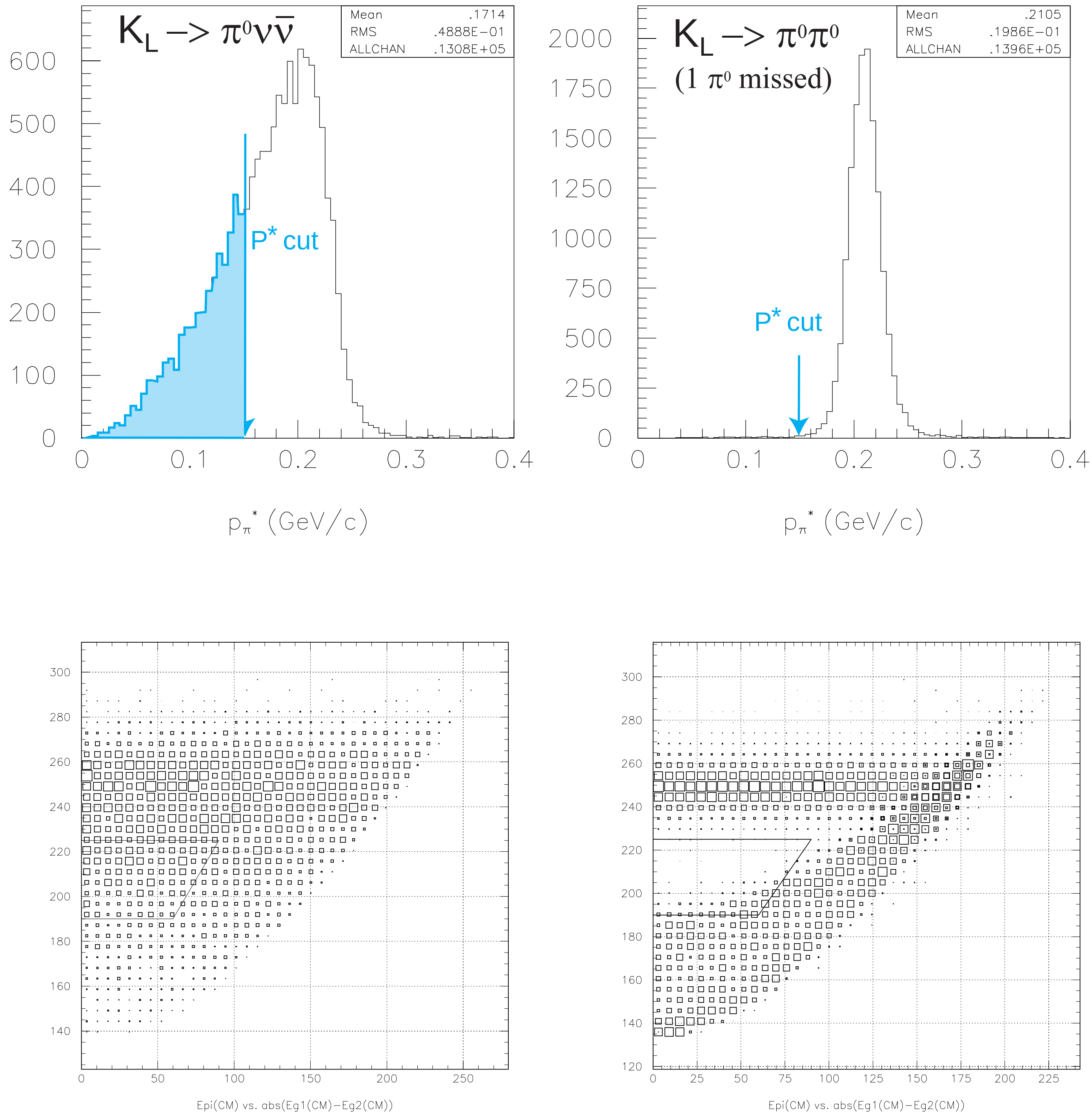
Most neutrons, off-momentum K_L put out of time

Most neutrons below π^0 production threshold

No hyperon background
- relatively few produced, energies low
- decay upstream of detector

Preradiator also serves as particle (γ) ID device

$K_L \to \pi^0\nu\bar{\nu}$ and $K_L \to \pi^0\pi^0$ identification



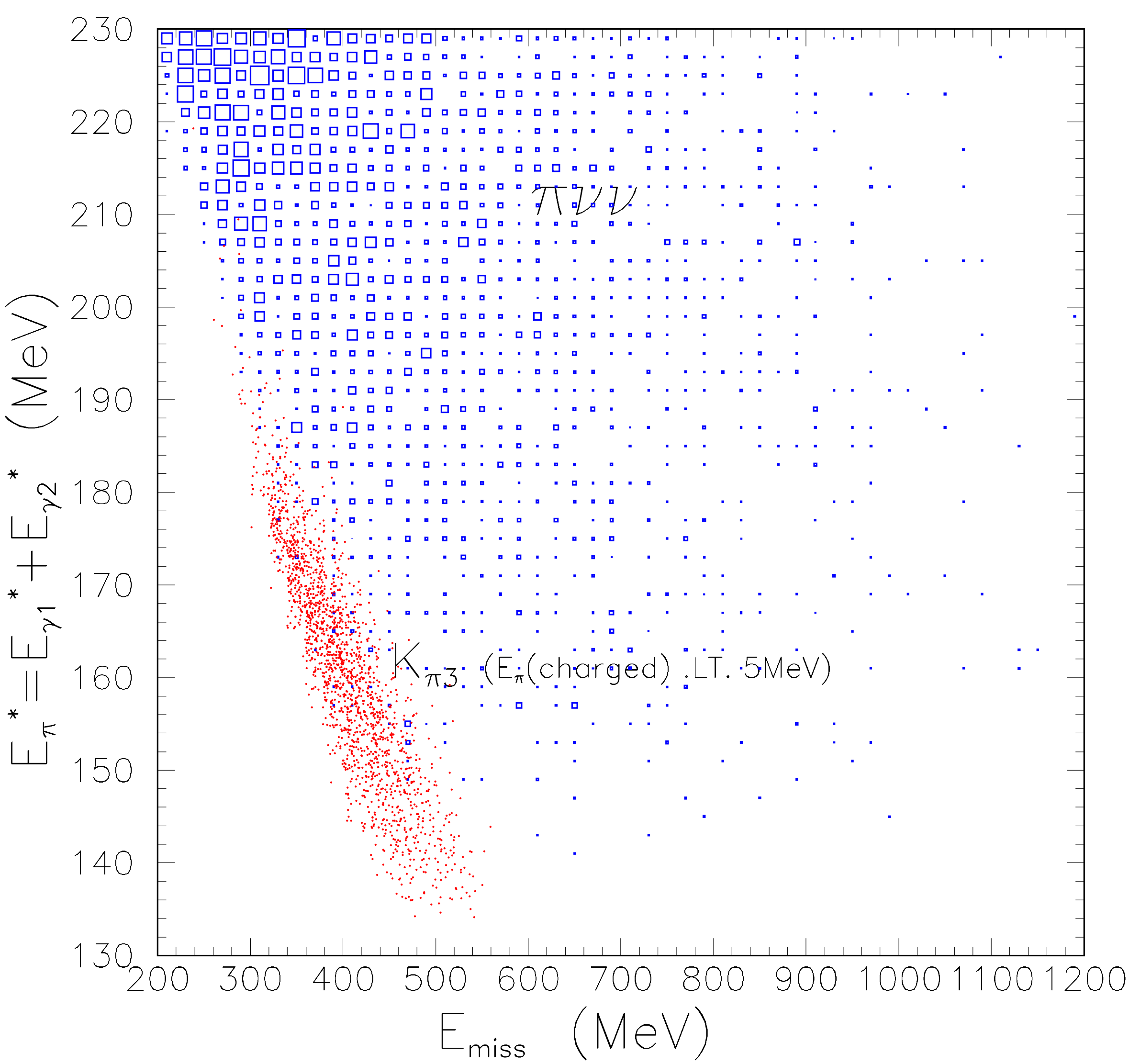
$K\pi3$ background

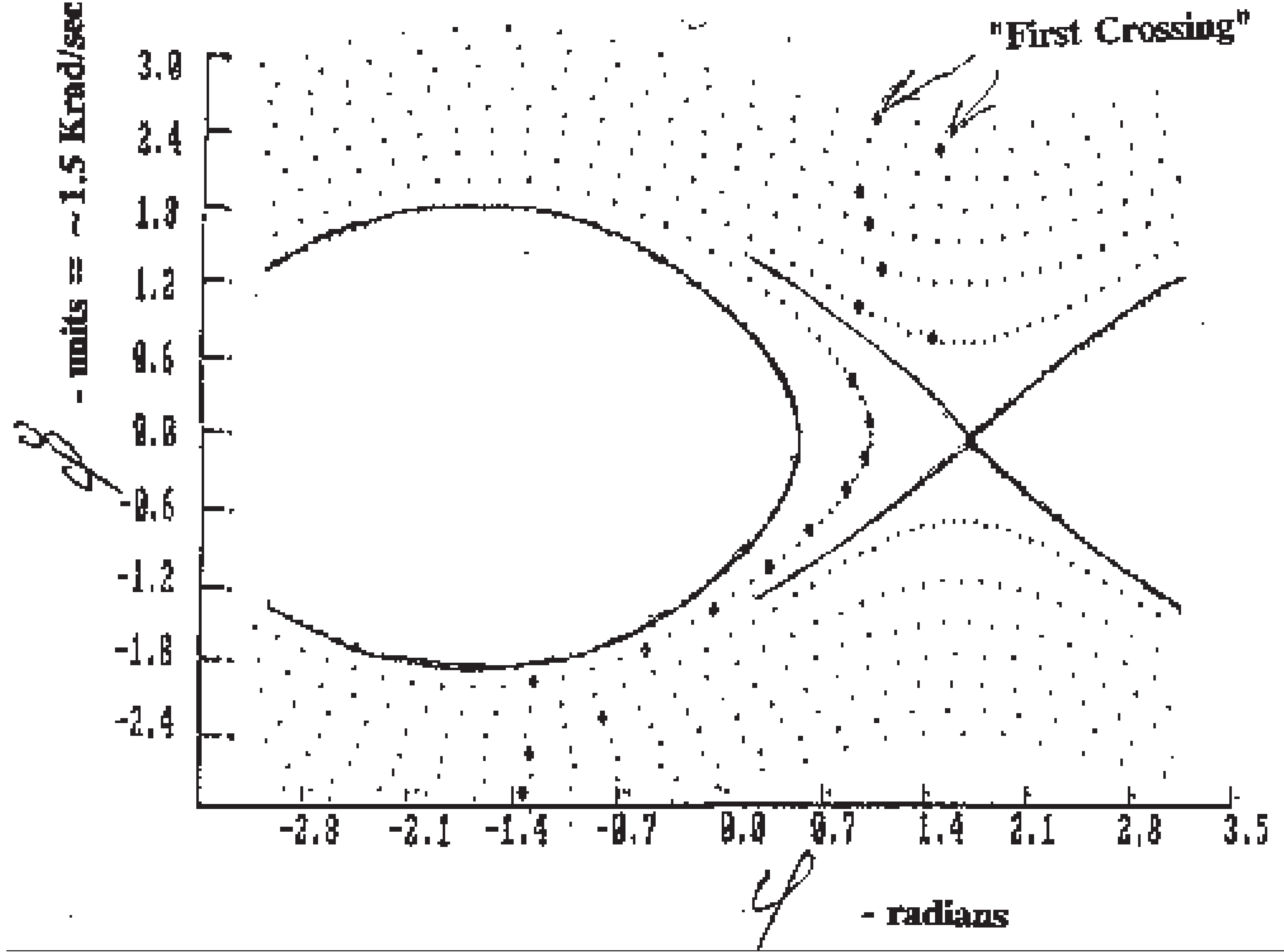
$K_L \to \pi^0\pi^0\pi^0$ not a problem since easy to veto

But $K_L \to \pi^0\pi^+\pi^-$ with slow charged tracks dangerous

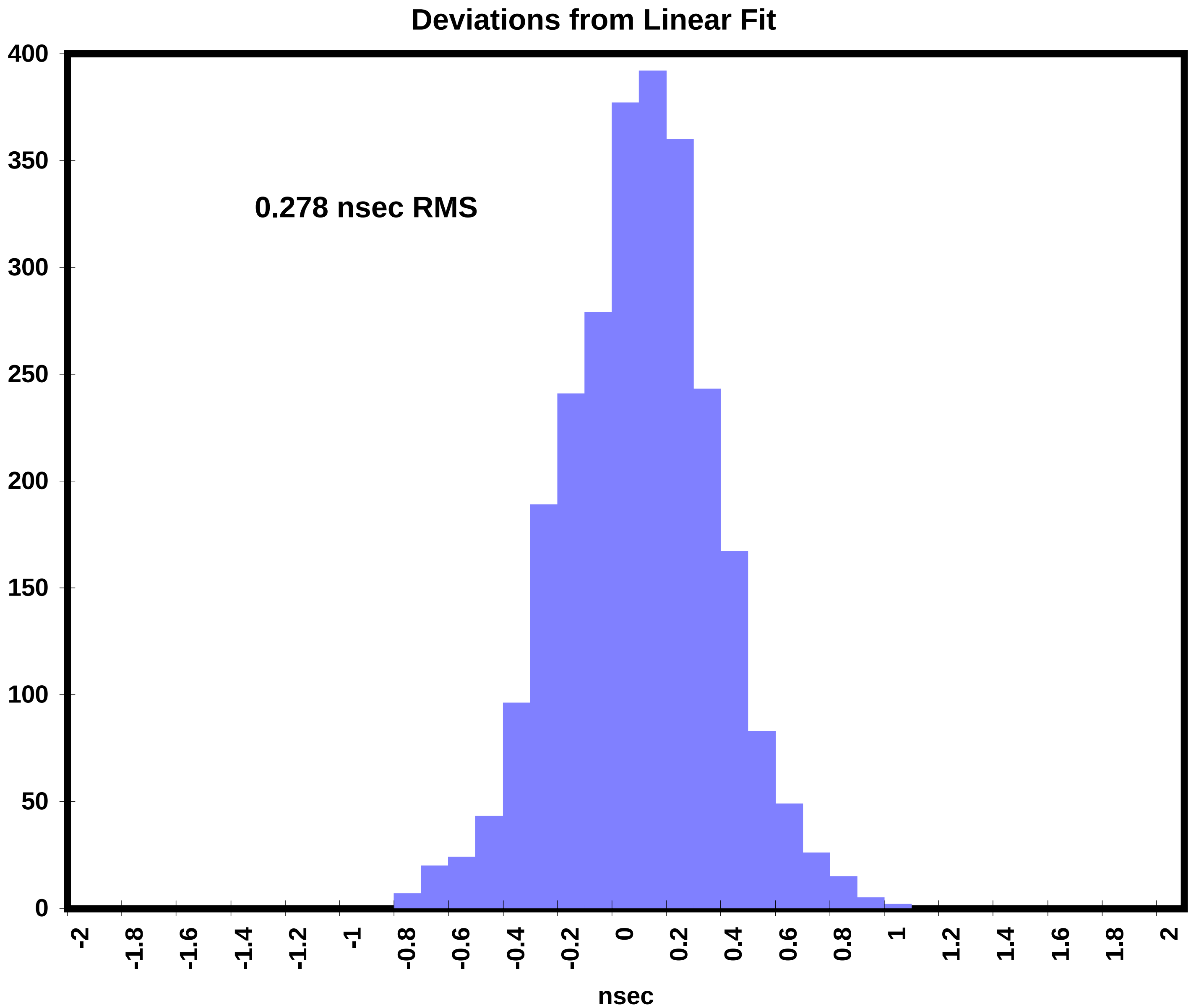
Once again kinematics comes to the rescue

Graph shows events with $\pi^\pm$ kinetic energy < 5MeV




"First Crossing"
- units = ~1.5 Krad/sec
3.0
2.4
1.8
1.2
0.6
0.0
-0.6
-1.2
-1.8
-2.4
-2.8
-2.1
-1.4
-0.7
0.0
0.7
1.4
2.1
2.8
3.5
- radians

Test of microbunching on extraction at AGS

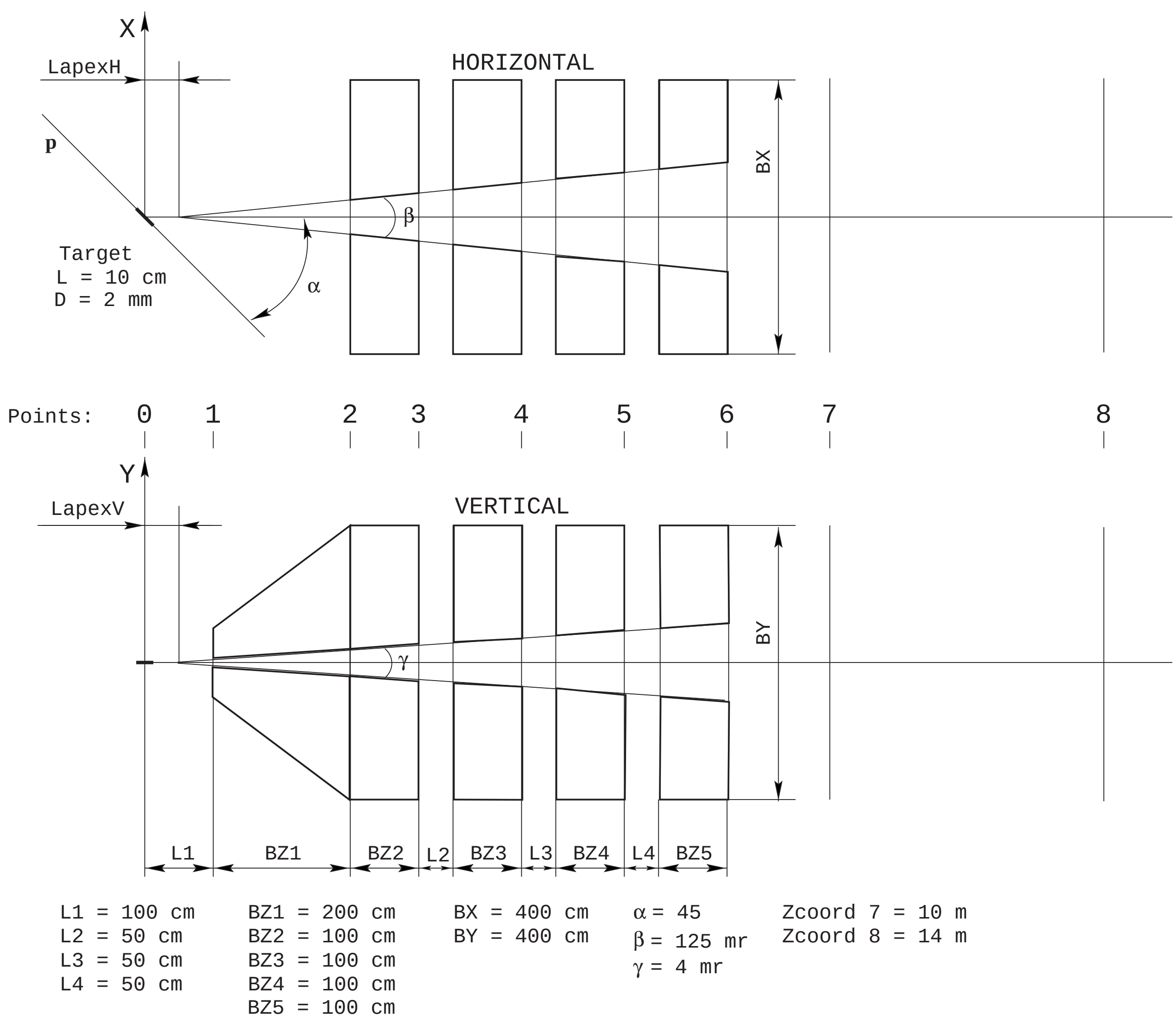


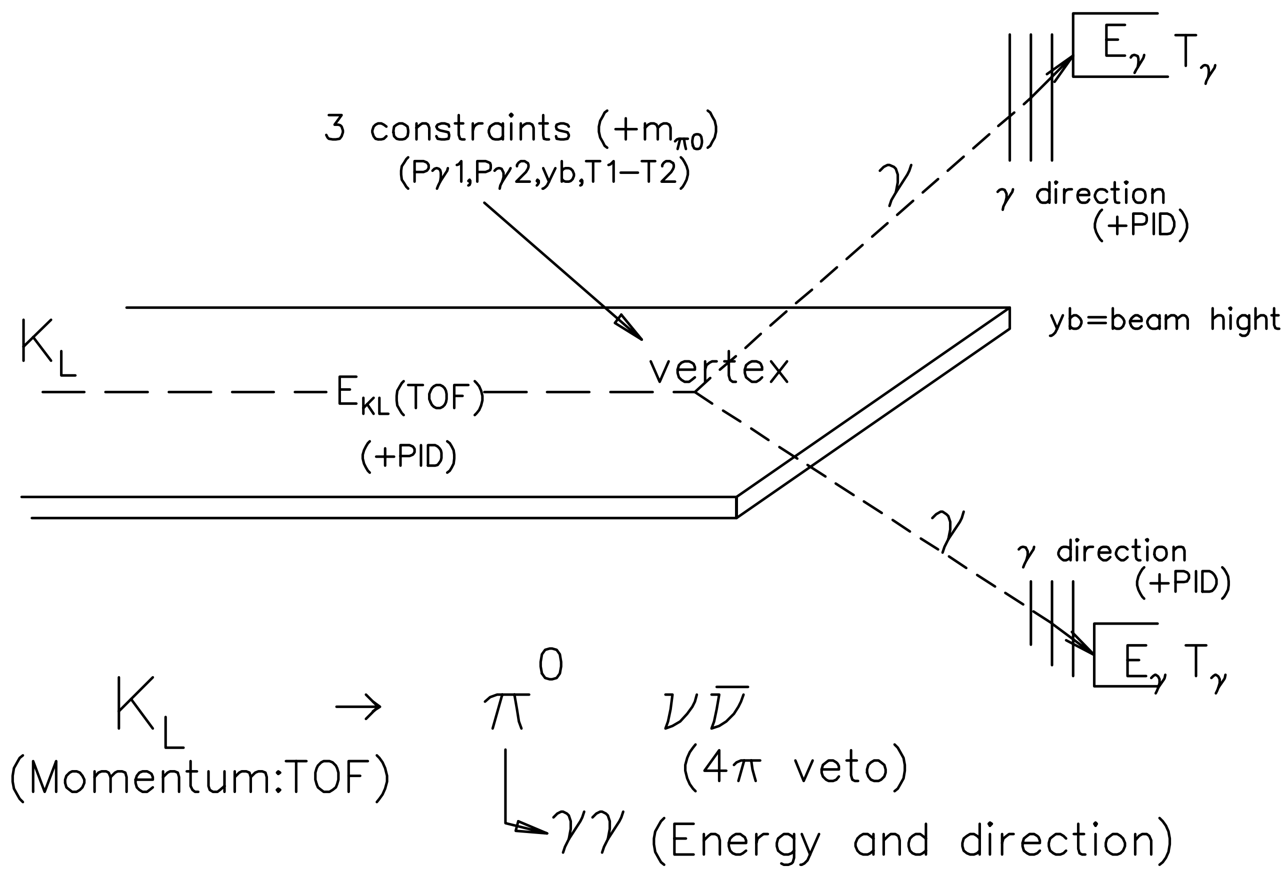
Technique now well established

Very successfully used to smooth AGS spill

KOPIO Beam

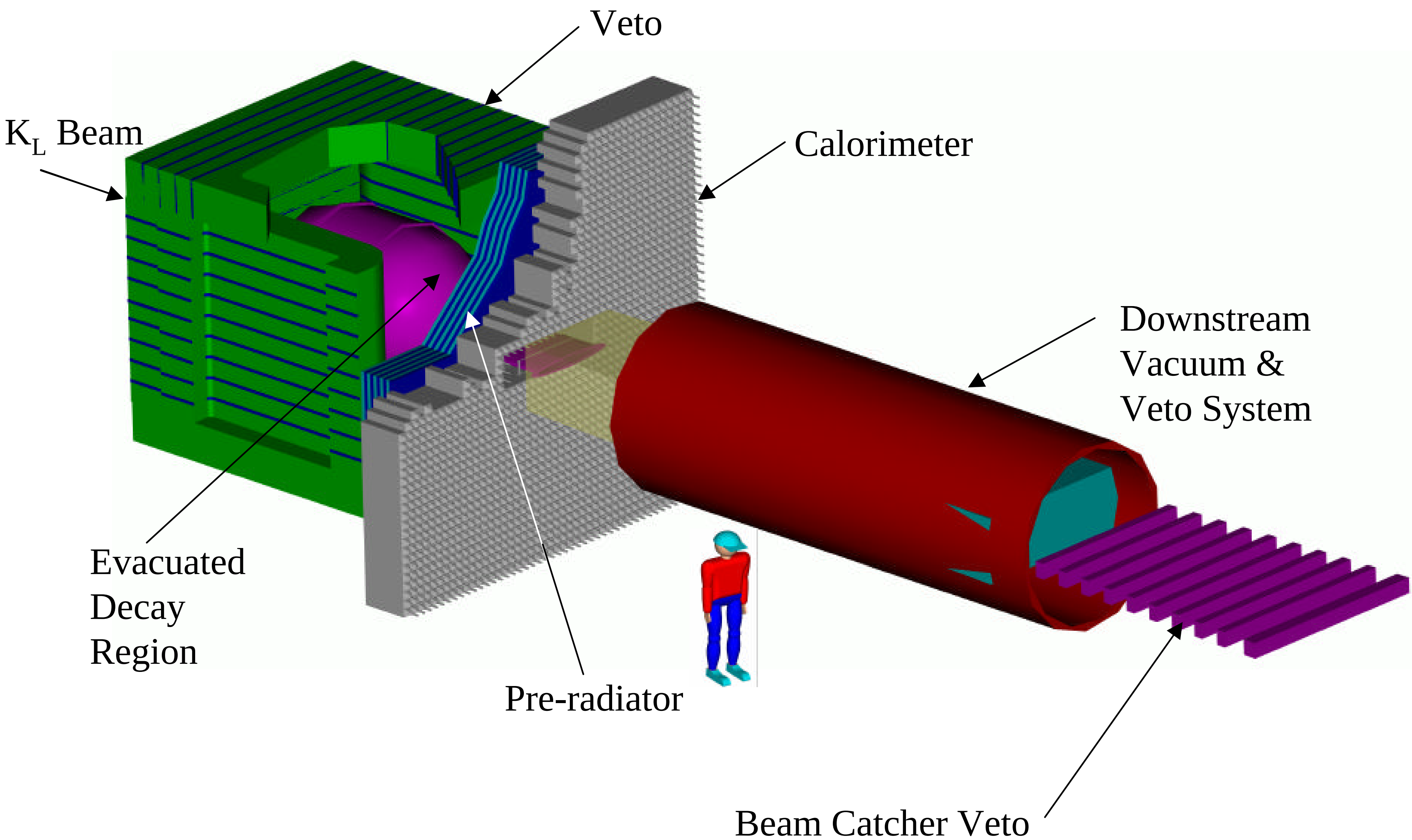
Microbunched at 25 MHz (< 200ps bunches)
To get K_L slow enough to do TOF, go to $40^o - 45^o$
To get enough K_L need 100 TP/spill
Gives 2.6×10^8 K_L, of which 4.2×10^7 decay usefully
But 10^{11} neutrons, luckily mainly very low energy
Need to reduce beam halo to $< 10^{-4}$ of in-beam value
For clean conditions accept only 1-decay μ-bunches
Optimization gives $\sim$ 3-second spill length

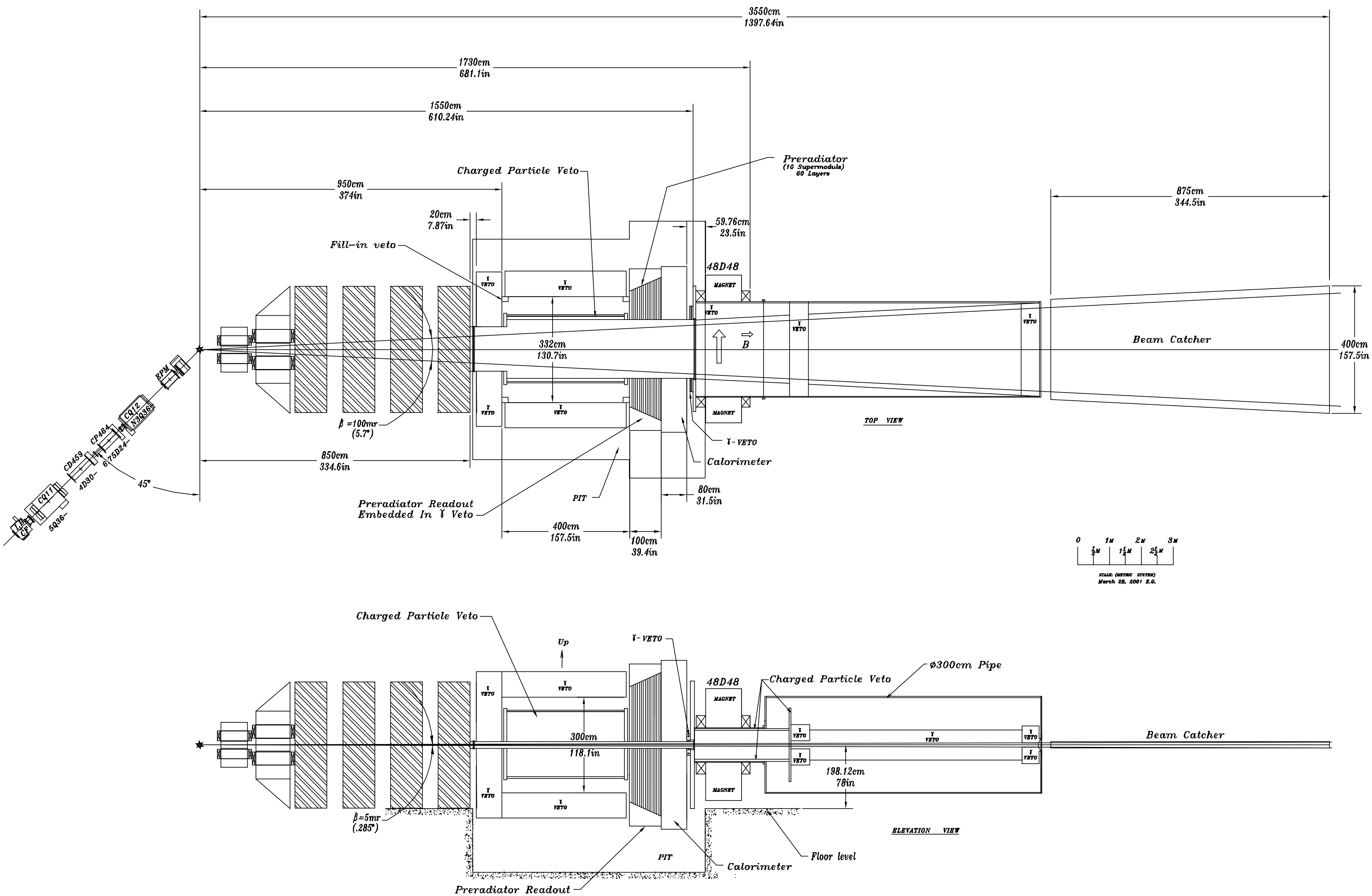




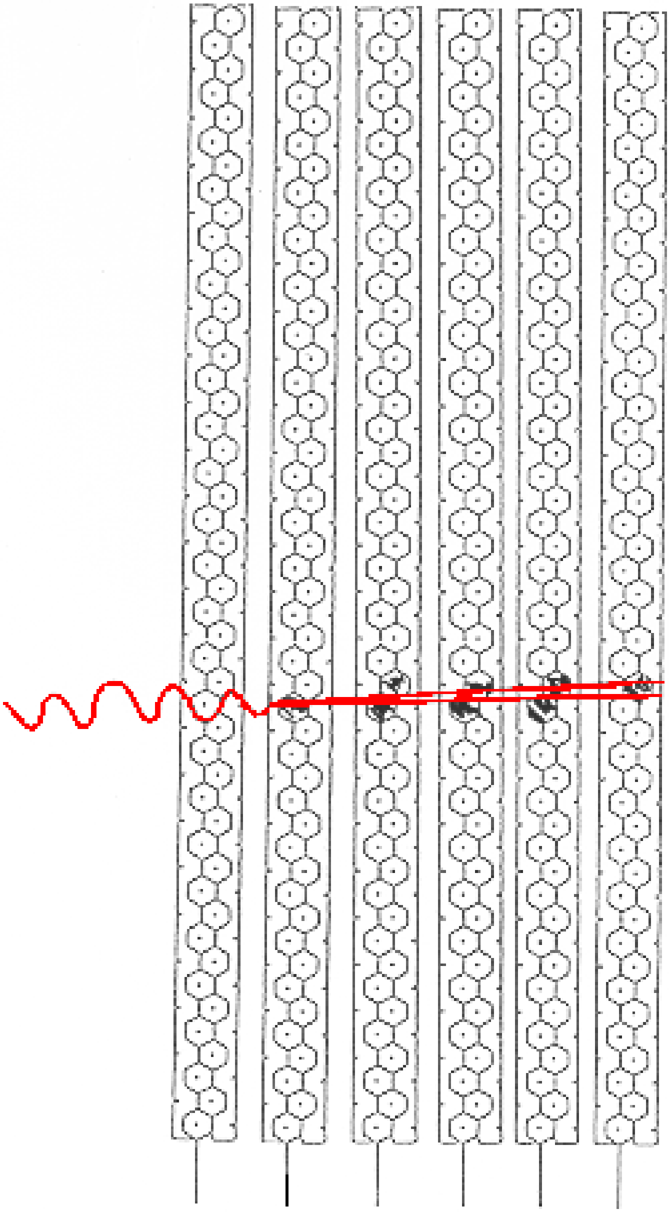
3 constraints (+m$_{\pi 0}$)
(Pγ1,Pγ2,yb,T1−T2)
γ
E_γ T_γ
γ direction
(+PID)
yb=beam hight
K_L
vertex
E_{KL}(TOF)
(+PID)
γ
γ direction
(+PID)
E_γ T_γ
$K_L \rightarrow \pi^0 \nu\bar{\nu}$
(Momentum:TOF)
(4π veto)
$\gamma\gamma$ (Energy and direction)

KOPIO


Veto
K_L Beam
Calorimeter
Downstream Vacuum & Veto System
Evacuated Decay Region
Pre-radiator
Beam Catcher Veto

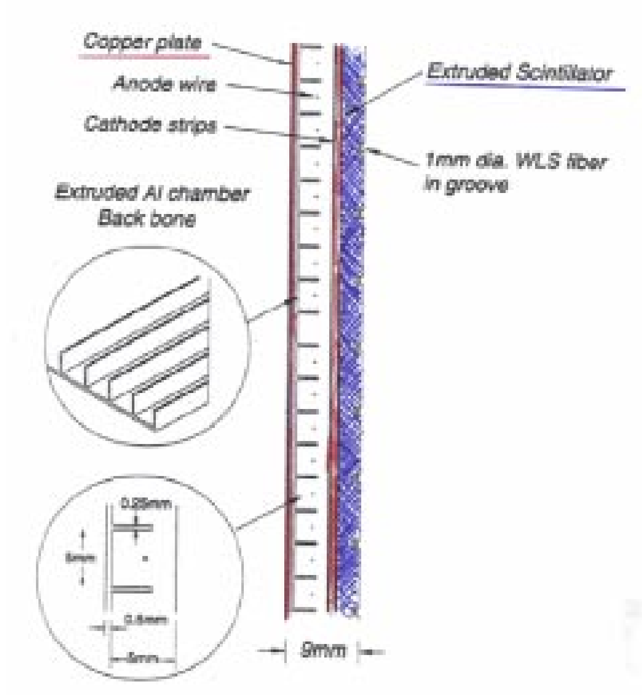


KOPIO EXPERIMENTAL APPARATUS



Photon angle measurement

Principle: track 1st converted pair in low-density preradiator

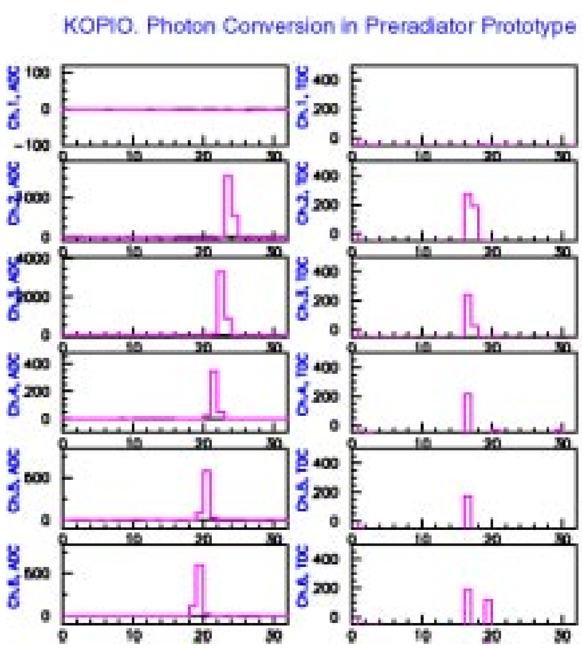


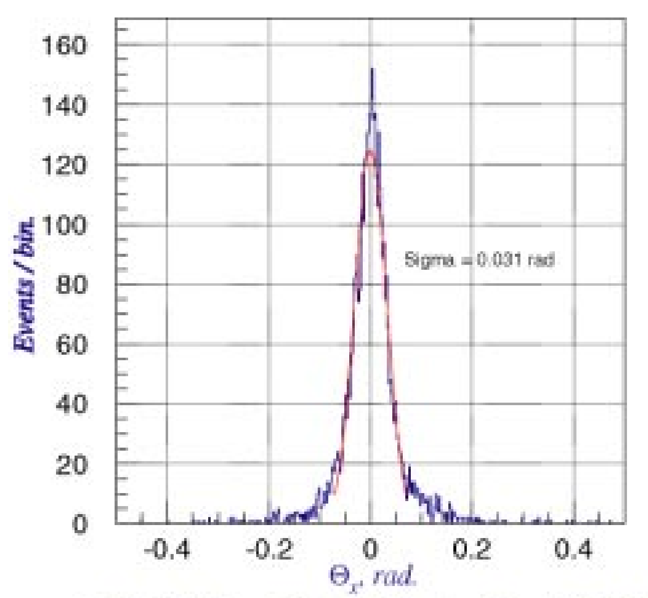
64 layers of chamber + scintillator
- each station $0.03X_0$

We will need $\sigma_\theta \sim 30$mr

MC indicates this can be done

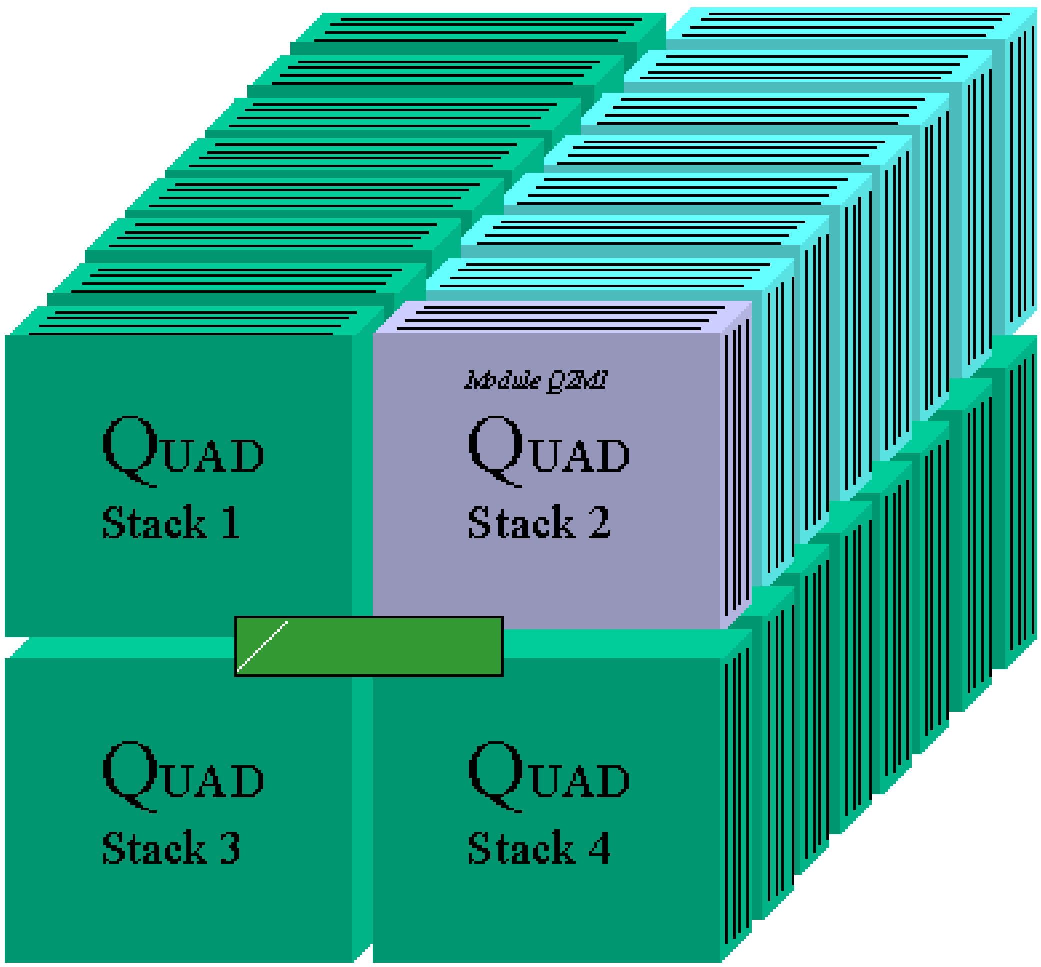
Prototype tests in the LEGS tagged γ beam at the BNL NSLS confirmed this:





Θ_x distribution of detected photons. $E_\gamma = 150$ MeV.

KOPIO Preradiator



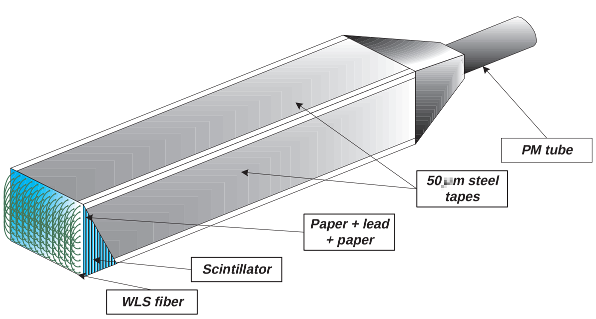
Calorimeter

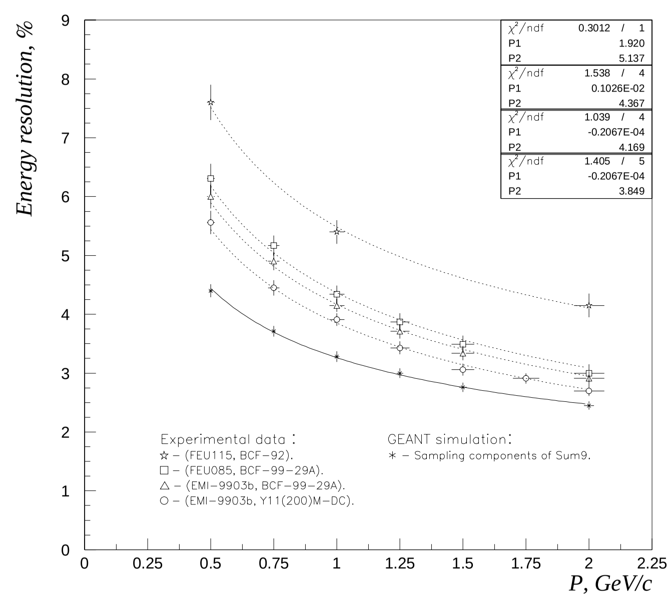
Need $\sigma_E/E \propto 0.03/\sqrt{E}$

Use well-understood shashlik technology

Better than $0.04/\sqrt{E}$ already demonstrated

MC indicates goal can be straightforwardly reached

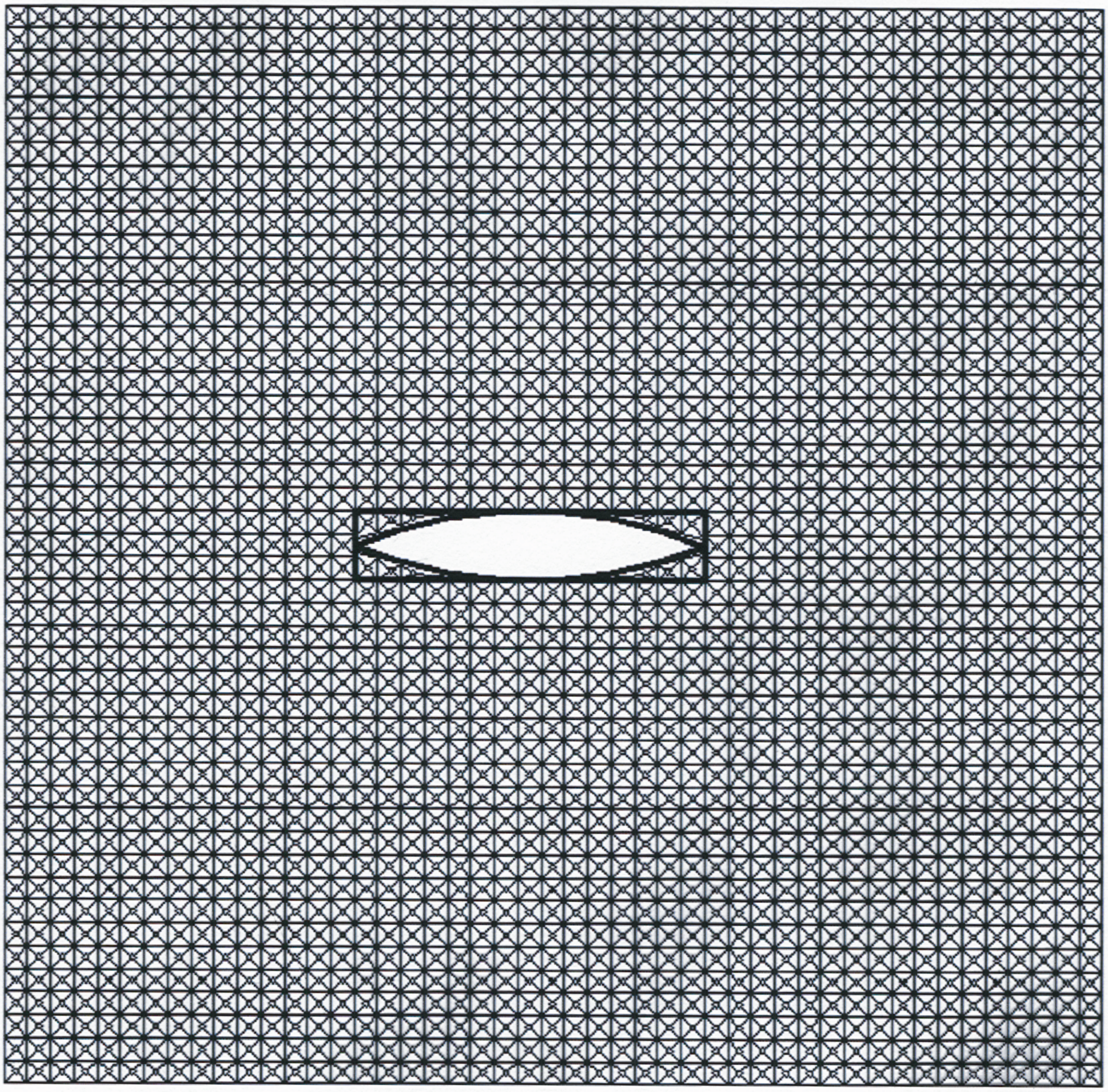




Note that **overall** σ_E depends strongly on preradiator

- MC of latest configuration indicates $\sigma_E/E \sim 0.027/\sqrt{E}$

KOPIO EXPERIMENTAL APPARATUS

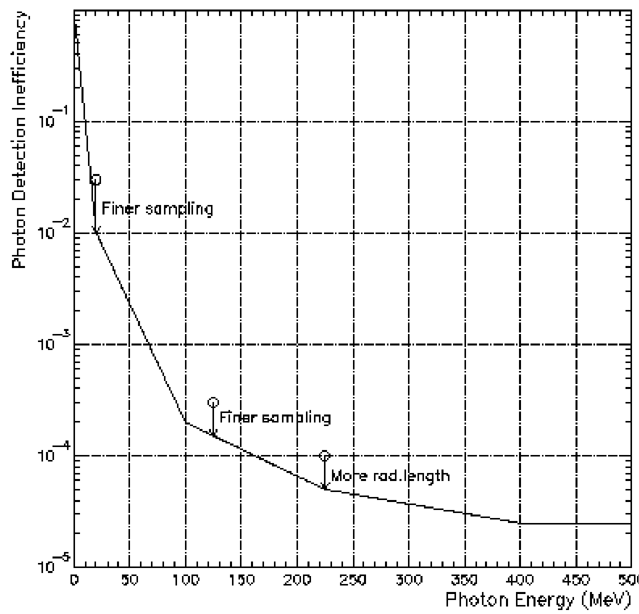


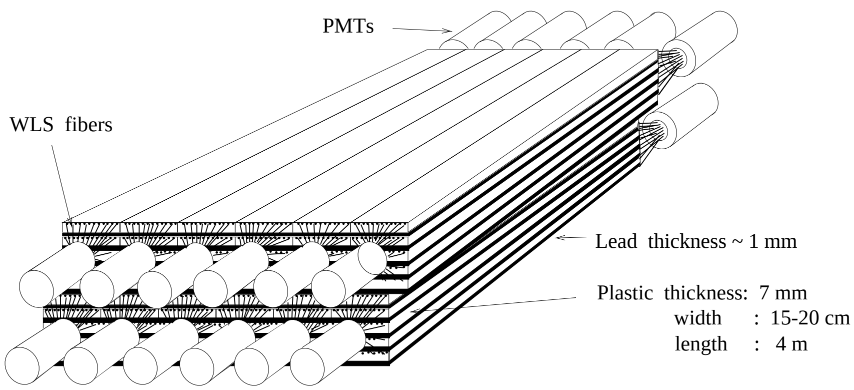
CALORIMETER
(END VIEW)

KOPIO Photon Veto

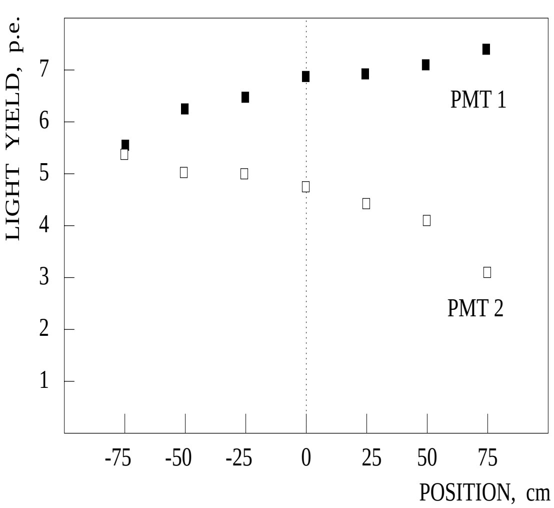
Require photon veto inefficiency only a little better than that already demonstrated in E787.

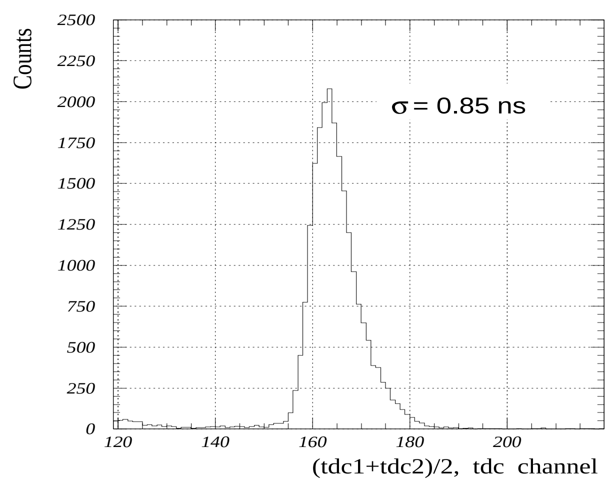
Technology similar, but wls readout gives better uniformity, brightness, and KOPIO will have more radiation lengths.

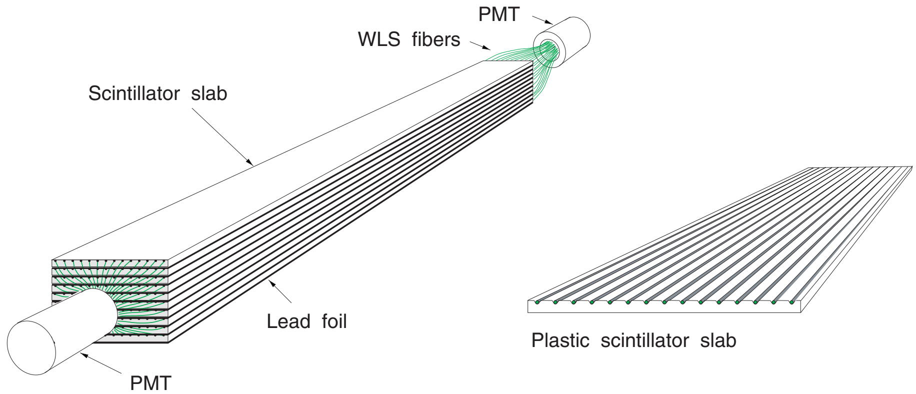




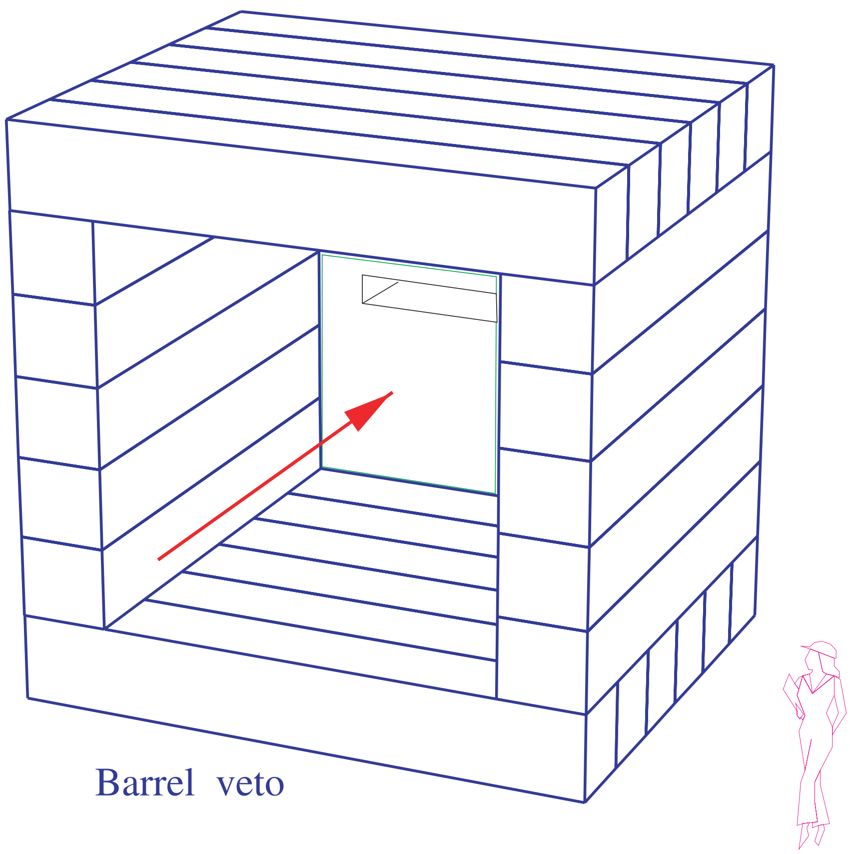
Prototype scintillators show required brightness, uniformity and time resolution:





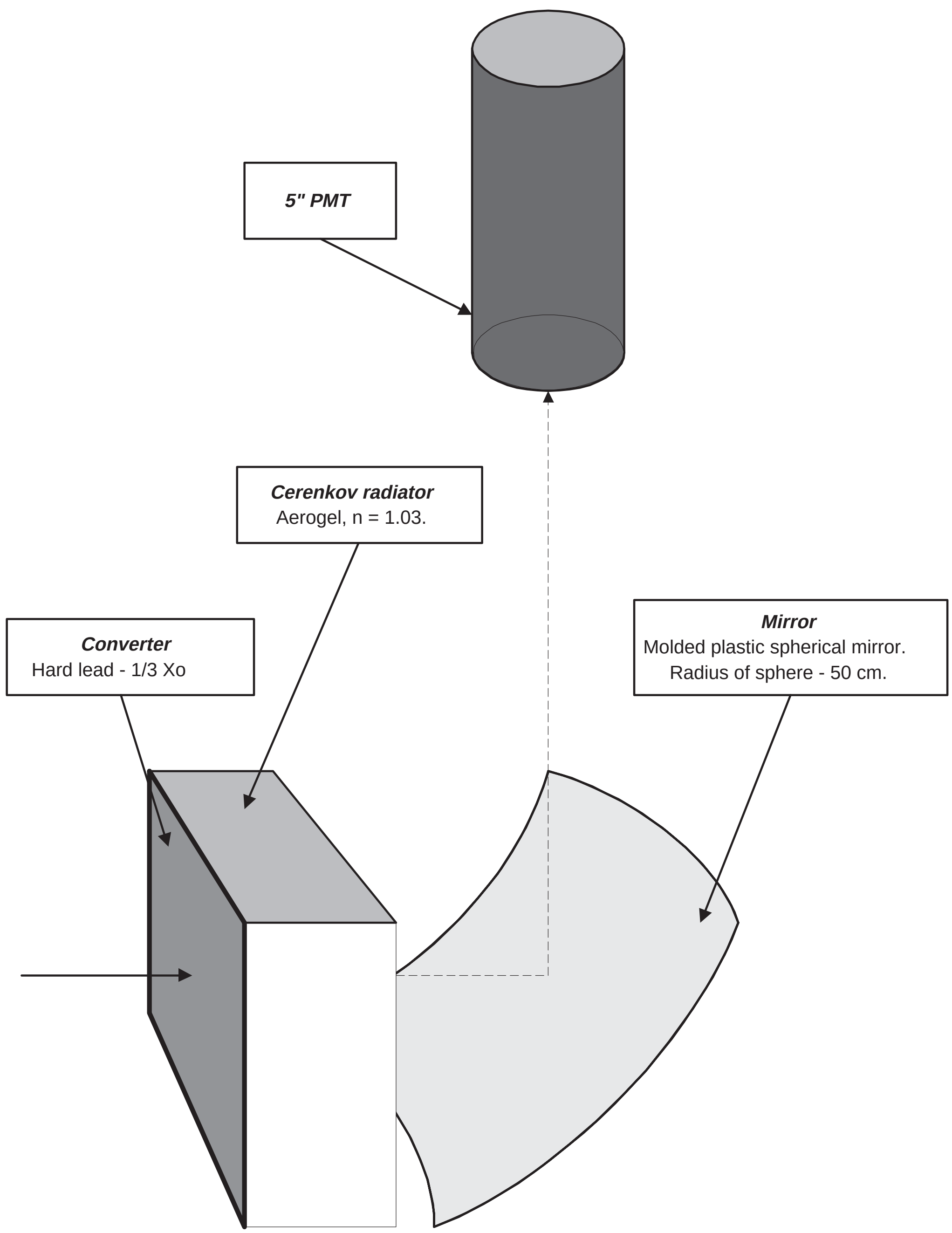


Schematic view of a veto sandwich module.

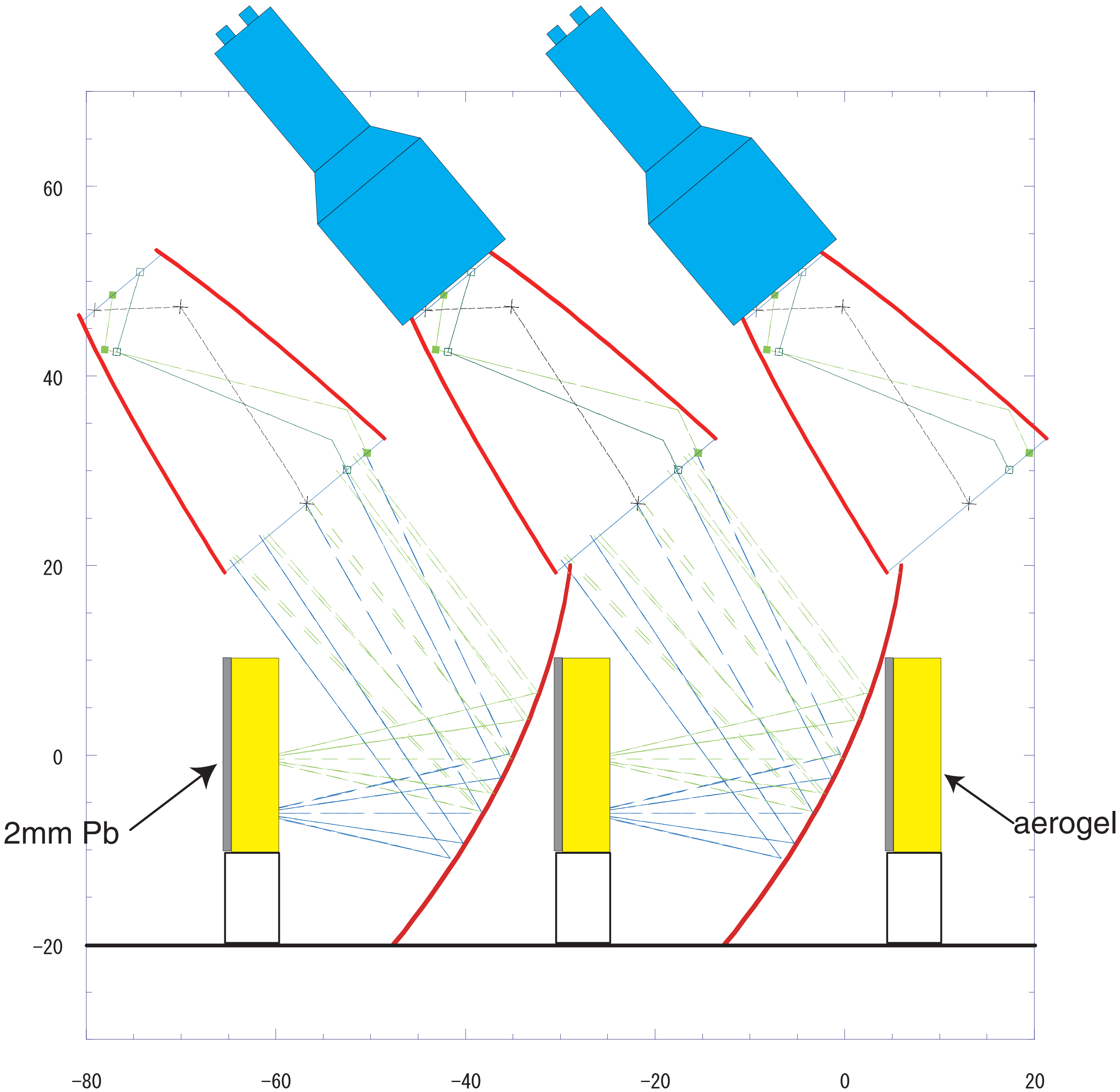


The view of the veto barrel assembled of about 750 modules.
Inner size of the veto is $3{:}5^2 \quad 3{:}5\,\mathrm{m}$, length is 4.2 m.

KOPIO Beam Catcher Module



KOPIO Beam Catcher Photon Veto



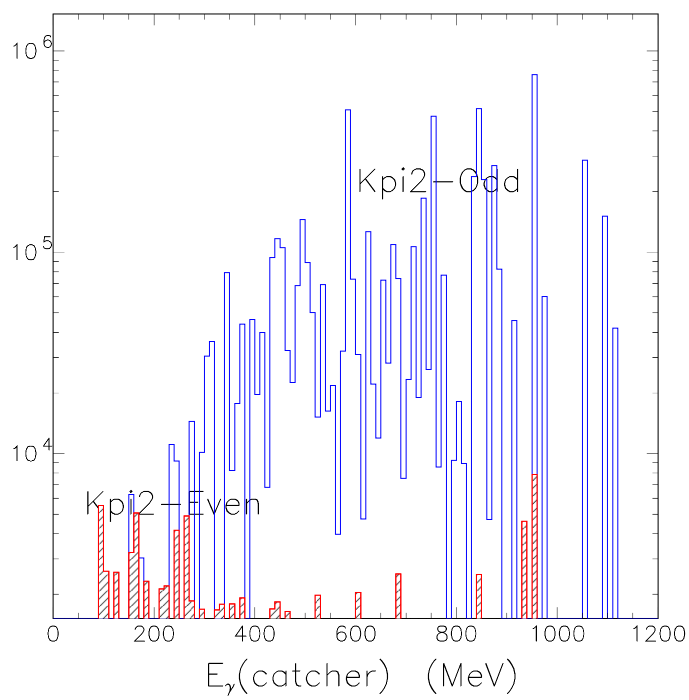
Demands on the KOPIO Beam Catcher

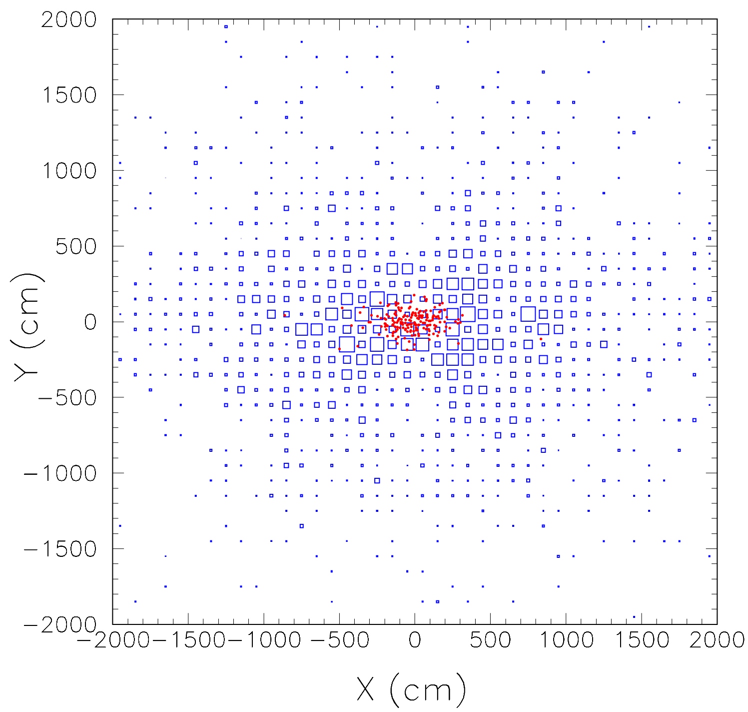
Not easy to veto γ's in flux of 3×10^{10} Hz of neutrons

Aerogel insensitive to large majority of neutrons
- Demand hits in 3 successive layers

After kinematic cuts, photons into the catcher are mainly stiff

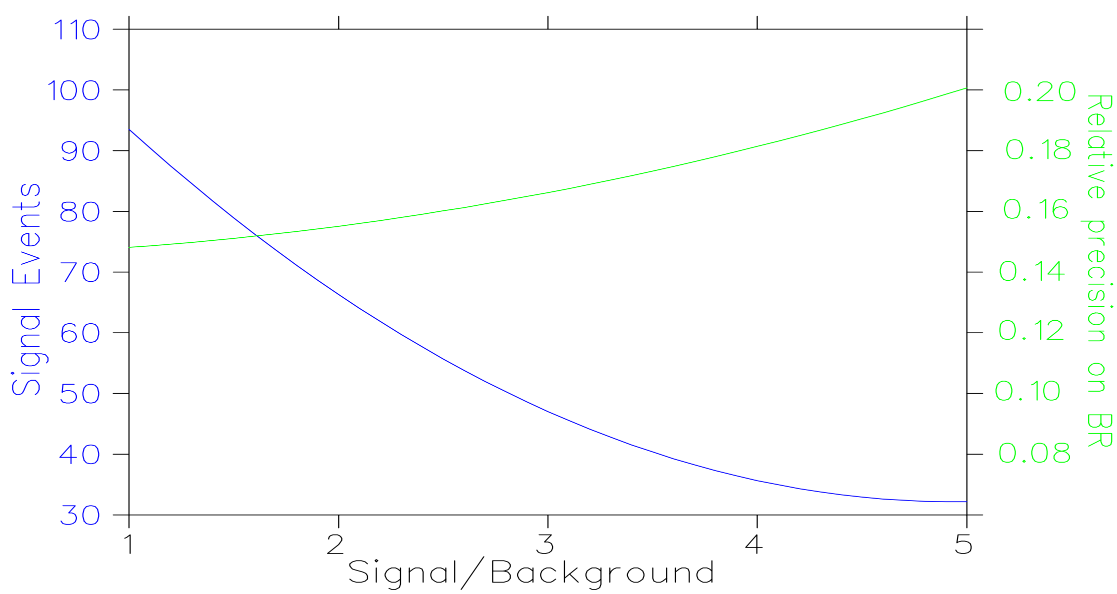
Also, if willing to lose 20% in acceptance **don't need catcher!**





KOPIO Signal & Background

Process	Modes	Main source	Evts
$K_L \to \pi^0 \nu \bar{\nu}$			65
K_L decays $(\bar{\gamma})$	$\pi^0\pi^0,\ \pi^0\pi^0\pi^0,\ \pi^0\gamma\gamma$	$\pi^0\pi^0$	24
$K_L \to \pi^+\pi^-\pi^0$			9
$K_L \to \gamma\gamma$			0.04
K decays $(\overline{charge})$	$\pi^\pm e^\mp \nu,\ \pi^\pm \mu^\mp \nu,\ \pi^+\pi^-$	$\pi^- e^+ \nu$	0.06
K decays $(\bar{\gamma},\ \overline{charge})$	$\pi^\pm l^\mp \nu\gamma,\ \pi^\pm l^\mp \nu \pi^0,\ \pi^+\pi^-\gamma$		0.1
Other particle decays	$\Lambda \to \pi^0 n,\ K^- \to \pi^-\pi^0,\ \Sigma^+ \to \pi^0 p$	$\Lambda \to \pi^0 n$	0.03
Interactions	$n,\ K_L,\ \gamma$	$n \to \pi^0$	0.5
Accidentals	$n,\ K_L,\ \gamma$	$n,\ K_L,\ \gamma$	1.5
Total Background			35



Conclusions

$K_L \to \pi^0 \nu \bar{\nu}$ is a window into the heart of CP violation
- directly determines the Jarlskog Invariant
- complementary to B system results

KOPIO designed to collect ~ 50 evts with low bckgnd in 3 yrs
- can give $7-8\%$ measurement of $Im\lambda_t$

Can explore a window from $\sim 6 \times 10^{-7}$ down to $\sim 10^{-12}$
- less than 1% of which is allowed by S.M.

Technique exploits favorable conditions available at AGS
- intense, μ-bunched beam
- running incremental to RHIC

Features highly effective constraints and cross-checks
Has been through several reviews

KOPIO capitalizes on experience (& personnel) of past exps
- AGS E787: similar vetoes, analysis techniques
- AGS E865: similar rates, calorimetry

Practical, cost effective, solutions for the technical challenges
- instrumentation based on existing detectors where possible or, where necessary, on tested prototypes

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